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Pedestrian risk index for Irbid city, Jordan

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Abstract

Engineers develop pedestrian accident models to reduce the risk of being involved in a traffic accident. Many factors entered to predict accidents incidence. The research results indicate that there is a significant relationship between pedestrian exposure, traffic volume, and accident incidence, which yields r-squared 0.71 at a 5 per cent level of significance. The availability of detailed data about pedestrian exposure (volume) is a major challenge facing pedestrian safety advocates & urban planners. Many techniques could be used to estimate exposure, space syntax methods were used in this paper to analyse streets network and predicts the movements' potentials. Using the space syntax approach in modelling pedestrian movements would allow planners to take more a proactive role in risk assessment when needed tools and resources are not available.

Keywords

Pedestrian risk, space syntax, pedestrian exposure, pedestrian traffic accidents.

1. Introduction

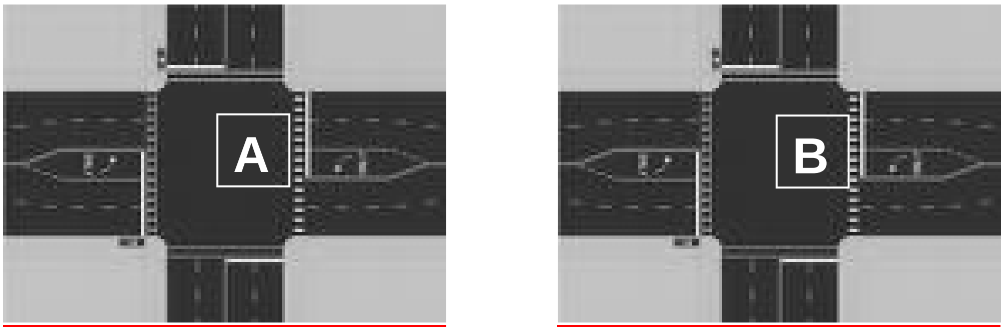
At all levels, whether at a national or an international level, road traffic accidents continue to be a growing problem. In connection with this, according to the World Health Organization's Global status report on road safety 2013, traffic fatalities are expected to be the fifth leading cause of death worldwide and road traffic injures will take the third place in the rank order of disease burden by 2020 (Organization, 2013).

The traffic accident rate in Jordan goes up together with the increasing number of motor vehicles and population size. In Jordan, above 274 people died while above 4,022 were crippled or injured in 2013 (Jordan Traffic Institute report, 2013). Moreover, pedestrian accidents recorded in Irbid, Jordan, were 621 which represent 15% of total accidents in Jordan in the same year. Even though those figures were declared based on statistical data from the authorities showing a hazardous situation, it seems insufficient work has been done to reduce this alarming accident rate. The formulation of the pedestrian risk index in Irbid is the first step in each project for traffic safety in the city. This step is usually overlooked in efforts and decisions being made to solve the problem. In many cases, dangerous locations were identified depending solely on the experience and opinion of decision makers. This has led to inaccurate identification of such sites. The formulation of the pedestrian risk index in Irbid on a scientific basis would help to obtain the optimal desired results and the lowest possible level of expenditures. Thus, this study attempts to define and quantify conditions detrimental to city safety in relation to pedestrian accidents in the city of Irbid. It identifies the high-risk locations by investigating the relationship between pedestrian accidents, pedestrian exposure and traffic volumes with the aim of analysing factors that have the highest contributions to pedestrian accidents.

1.1 Exposure to Risk

In the field of pedestrian safety, risk analysis involves assessing factors that contribute to the danger that a pedestrian is facing from a vehicle (Greene-Roesel, Diogenes, & Ragland, 2007). Many factors could contribute to pedestrian risk, collecting information about the physical characteristics of the street, such as a lack of sidewalks, behavioural issues, environmental variables, as well as pedestrian exposure information is a crucial component of understanding the risk that pedestrian could face in the streets (Greene-Roesel, Diogenes, & Ragland, 2007; Raford & Ragland, 2003, 2005). Pedestrian exposure is a concept that refers to the amount of pedestrian involved in a traffic accident. It is measured by pedestrian volumes as expressed in units of pedestrians per hour or per year (Greene-Roesel et al., 2007; Liu & Griswold, 2009).

Raford & Ragland (2003) demonstrate the concept of exposure as it relates to pedestrian risk, as shown in figure (1). That is, Intersection (A) experiences 10 collisions per year, with an average peak-hour pedestrian rate of 100 pedestrians per hour, while Intersection (B) experiences 20 collisions per year, but has an average peak-hour pedestrian rate of 1,000 pedestrians per hour.



Intersection A experiences 10 collisions per year, with an average annual pedestrian volume of 10,000 pedestrians per year.

Intersection B experiences 20 collisions per year, but has an average annual pedestrian volume of 100,000 pedestrians per year.

Figure 1. Pedestrian risk is a function of the number of annual pedestrian – vehicle accidents divided by the amount of pedestrian exposure (pedestrians per hour). Source: (Raford & Ragland, 2003)

Dividing the annual number of collisions by pedestrian volume rate (exposure) gives a measurement of relative risk and reveals that Intersection A experiences 0.1 annual collisions per pedestrian hour, while Intersection B experiences 0.02 annual collisions per pedestrian hour. These results reveal the importance of pedestrian volume data in determining the accident risk of streets and intersections. Many techniques have been applied in order to collect information about pedestrian volumes; pedestrian counts were used to represent pedestrian volumes at micro levels (at streets segments and intersections levels), while other techniques were applied to represent the whole city like pedestrian modelling and estimations. Pedestrian counts, for the most part, involve field observations and manual counts of pedestrians passing in the street. They may be carried out using video analysis (Ismail, Sayed, & Saunier, 2009; Kennedy, 2008). However, these manual observations are time consuming, limited in coverage and expensive. Recently, researchers have developed statistical models to estimate pedestrian volumes based on actual pedestrian counts and other indicators such as land use, transportation, street connectivity and demographic factors of an area.

These estimations can be generalized to express pedestrian volumes for entire city streets and intersections (Miranda-Moreno, Morency, & El-Geneidy, 2011; Schneider, Arnold, & Ragland, 2009). Kim, Ko & Lee (2013) review pedestrian volume modelling techniques. They discuss the sketch plan methods and network analysis approach. Sketch plan methods, which are larger in scope, predict pedestrian volumes through the use of pedestrian counts and the association of land use indicators and/or other transportation trip generators factors. On the other hand, network analysis approaches are the appropriate tools for a city-wide scale prediction of pedestrian movement. These techniques require the use of analysis software, such as UCL depthmap or visibility graph analysis software (Kim, Ko, & Lee, 2013).

Network analysis models that are based on space syntax theories have been widely used to estimate pedestrian and vehicle volumes for street segments and intersections over an entire city or neighbourhood (Greene-Roesel et al., 2007; Raford & Ragland, 2003, 2005). Several studies conducted using space syntax demonstrate its capability in predicting pedestrian flows with a high level of accuracy of 60 per cent to 80 per cent (Penn, Hillier, Banister, & Xu, 1998). Pedestrian movements in space syntax are usually studied with its association to the measurements of space accessibility. The techniques of linear map analyses that include the axial map analysis and the segment map analysis have been used in assessing the spatial network accessibility. An axial map can be defined as the least set of straight lines covering all routes of movement and making links to every unit on the system (B Hillier & J Hanson, 1984, pp. 17, 91 & 99). In this case, an axial line is not a real entity, but a form of representing potential routes of movement; also they are meaningful because they model the experience of users in space. A segment map is a refined version of an axial map, where axial lines are broken down into smaller segments at each intersection (Sailer & McCulloh, 2012). Axial and segment line maps determines the movement flows through spaces. This means lines and their connections are spatial representations of the social phenomenon of movement flows. Axial and segment line maps will be used to calculate overall properties of each spatial element, such as, integration and connectivity. Integration indicates how accessible the space is from other spaces in network system, while connectivity of a space indicates the number of spatial units directly connected to it. It is already reported in the literature that there is a strong correlation between movement densities on path and the syntactic values of this path defined by the axial map analysis (B. Hillier, 1996; B. Hillier & J. Hanson, 1984; Bill Hillier, Hanson, & Graham, 1987; B. Hillier & Vaughan, 2007; Rashid, 2012).

2. Research methodology

Irbid has been selected as a case study to investigate the characteristics of pedestrian accidents for three years (2005-2007). Geographic information system (GIS) software was used to locate each pedestrian accident on an Irbid street map. A separate analysis was conducted on the street grids. The study included three stages; analysis of estimated pedestrian volumes, analysis of estimated pedestrian accidents, and identification of high-risk prone locations. To accomplish the objective of this study, the methodology process consisted of the following five steps:

Pedestrian and vehicle count in a sample of 20 street segments that differ in their spatial significance, land use, and density.

(1) Data collection about factors that affect pedestrian accidents such as land use, street condition and other city planning characteristics.
(2) Spatial analysis of the urban street network using space syntax.
(3) Statistical analysis using multiple regressions to explain the relationship between the different variables.
(4) Generation of a current pedestrian risk map, and the predicted pedestrian risk map.

3. Results

3.1 Stage 1: Analysis of movement potentials.

An axial map was accomplished for Irbid City using UCL depthmap[1] software (Turner, 2004). The map includes 2,539 lines, each of them connected to other lines with an average 4.78 of axial connectivity. Space syntax properties (global and local integration measurements) identified King Hussein Street (3.99) as a dominant integrated street of its surrounding area as shown in Figure 2. Other measurements such as connectivity, intensity and choice also were calculated to understand which measurement had the strongest correlation with pedestrian volumes.

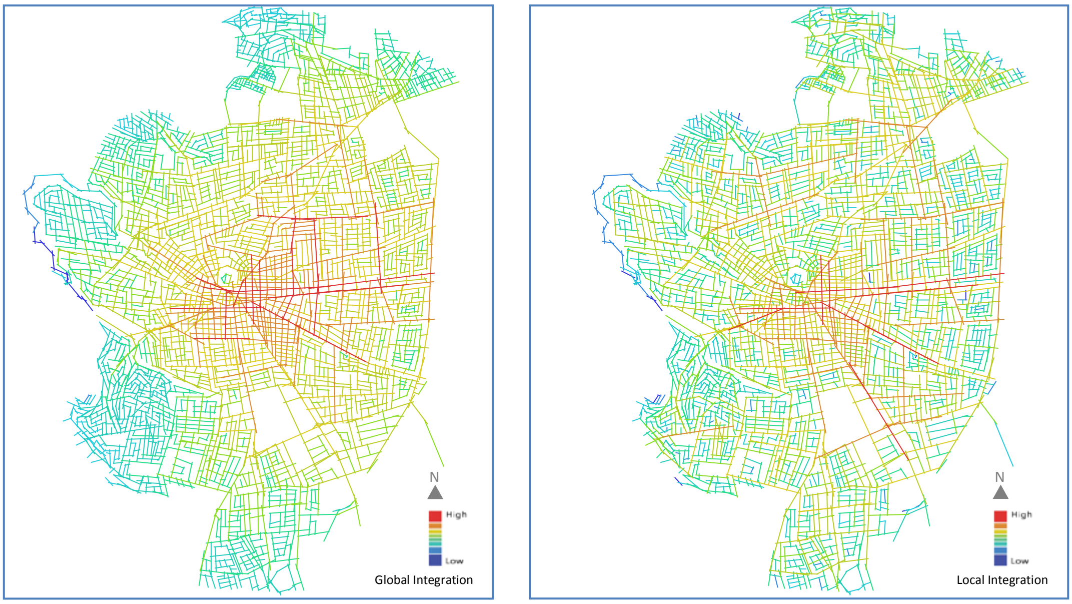


Figure 2. Global (left) and local integration map of Irbid (Source: author).

3.1.1 Pedestrian counts survey

In order to analyse the distribution of pedestrian activity in the area, a set of 20 continuous paths were assigned in Irbid to pedestrian counts. Observers recorded the number of pedestrian movements expressed as pedestrian volume per hour. Counting pedestrians was based on 15 minute time intervals for three hours (Zegeer et al., 2005). The counts were conducted on sunny working days in the middle of the week (Monday, Tuesday, and Wednesday) between peak hours 11:00 a.m.-2:00 p.m. This is in order to represent a normal pedestrian activity that occurs during middle working days (Table 2).

No	Name	INTn	INTr3	CONN	Choice	Intensity
1	Fadel Al Dalgamony St	1.147	2.99	10	2.14	0.512
2	AL Sina'ah Street	1.230	3.21	17	5.95	0.537
3	Dair Yaseen Street	1.211	2.93	6	1.115	0.531
4	Fo'ara Street	1.152	3.36	16	6.88	0.516
5	Bushra Street	1.402	3.74	25	4.98	0.588

[1] Depthmap is spatial network analysis software available at: http://www.spacesyntax.net/software/ucl-depthmap/.

6	Queen Zain Al Sharaf	1.257	2.81	7	.731	0.497
7	Prince Nayef Street	1.427	3.73	23	2.74	0.598
8	Firas AL Ajlouny Street	1.232	3.12	15	2.75	0.549
9	Prince Rashed alHassan Street	1.346	3.20	12	1.03	0.525
10	Feras Al Ajloni Street	1.358	3.24	12	1.85	0.526
11	Emam Malek Street	1.399	3.22	16	1.98	0.557
12	Abed Qader Alhussainy St	1.342	3.35	12	2.63	0.563
13	Al Rasheed Street	1.279	3.39	17	.947	0.535
14	Abedel Hameed Sharaf St	1.208	3.07	13	1.84	0.512
15	Mohammad Hijazi Street	1.397	3.41	12	1.05	0.556
16	Al Qudus Street	1.306	3.16	10	1.21	0.552
17	Omar Bin Abed AlAziz St	1.282	3.56	16	6.70	0.584
18	Abedel Hameed Sharaf St	1.206	3.19	16	2.45	0.518
19	Queen Noor Al Hussain St	1.285	3.34	11	7.67	0.564
20	AL- Quds Street	1.183	3.59	21	1.5	0.529

Table 2. 20 Streets were assigned for pedestrian movements modelling.

To create the pedestrian volume prediction model, a multivariate stepwise regression analysis was implemented. The independent variables are space syntax properties (global integration, local integration, connectivity, choice and intensity values) and land use variable. Based on this multivariate regression analysis, a model for pedestrian volume can be specified that predicts the pedestrian movement distribution across the entire city's street network. Table 3 shows the variable correlations and the coefficients used to create the model prediction formula. The correlation coefficients as in Figure 3 shows that the local Integration (R3) had a high positive correlation with the total number of pedestrian movement which yields a coefficient of determination R-square equal 0.745 (P value < 0.001). The model indicates that local integration (R3) is an important variable in explaining 75 per cent of the total variation in the pedestrian volume.

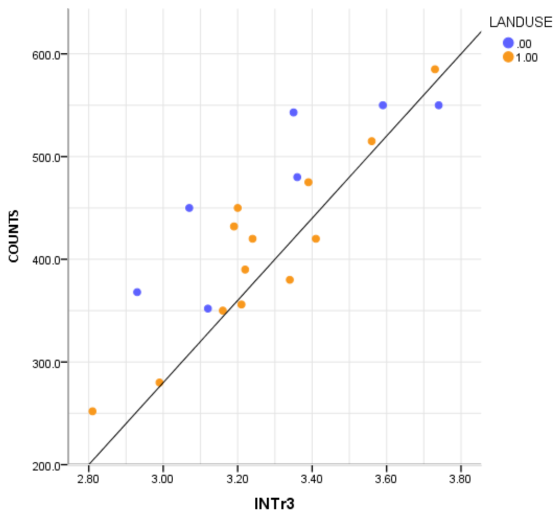


Figure 3. Scatter diagram showing the relation between observed pedestrian movement per peak hour and local integration R3.

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.863[a]	.745	.731	47.36152
2	.902[b]	.814	.792	41.68453

a. Predictors: (Constant), INTr3

b. Predictors: (Constant), INTr3, LANDUSE

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	-612.754	144.109		-4.252	.000
	INTr3	317.834	43.810	.863	7.255	.000
2	(Constant)	-553.900	129.006		-4.294	.000
	INTr3	309.598	38.700	.841	8.000	.000
	LANDUSE	-48.981	19.613	-.262	-2.497	.023

a. Dependent Variable: COUNTS

Table 3: Model variables summary and coefficients

<u>Model (1): Pedestrian volume regression equation:</u>

APPV = - 612.754 + 317.834 INTr3; R Squared = 0.745…………………………… (1)

Where, APPV= Average Peak Hour Pedestrian Volume and INTr3=Integration (R3)

The inclusion of a land use variable increased the coefficient determination from 0.745 to 0.814 (P value F-change = 0.023). The model shows that pedestrian volume is directly proportional to land use type. Commercial streets (as an example, Prince Nayef Street) have been found to have a higher rate of pedestrian movements than residential streets for selected street samples.

<u>Model (2): Pedestrian volume regression equation:</u>

APPV = - 553.900 + 309.598 INTr3 - 48.981 LANDUSE; R Squared = 0.814…… (2)

Where, APPV= Average Peak Hour Pedestrian Volume and INTr3=Integration (R3)

3.2. Stage 2: Pedestrian accidents modelling

Table 4 presents the 20 routes assigned to predict pedestrian accidents, each route expressed by average pedestrian volume per peak hour (APPV), local integration values, average daily traffic volume (ADT), street width, street length and sidewalk condition.

No	Name	APA	COUNTS	INTr3	ADT	Width (m)	Length (m)	Sidewalk Condition
1	Fadel Al Dalgamony St	2.000	280	2.99	24268	30	800	0
2	AL Sina'ah Street	1.000	356	3.21	11882	20	100	1
3	Dair Yaseen Street	1.667	368	2.93	16798	20	210	1
4	Fo'ara Street	1.000	480	3.36	11885	16	400	0

5	Bushra Street	).667	550	3.74	10400	16	970	1
6	Queen Zain Al Sharaf	?.000	252	2.81	?0305	40	100	0
7	Prince Nayef Street	0	585	3.73	2636	10	390	1
8	Firas AL Ajlouny Street	l.000	352	3.12	15572	20	190	1
9	Prince Rashed alHassan St	).667	450	3.20	8961	12	300	1
10	Feras Al Ajloni Street	l.000	420	3.24	15467	20	560	0
11	Emam Malek Street	).667	390	3.22	9330	18	260	1
12	Abed Qader Alhussainy St	).667	543	3.35	8961	14	310	0
13	Al Rasheed Street	l.333	475	3.39	12437	12	190	1
14	Abedel Hameed Sharaf St	l.333	450	3.07	16254	20	300	0
15	Mohammad Hijazi Street	l.000	420	3.41	17305	18	140	0
16	Al Qudus Street	l.333	350	3.16	19305	30	100	0
17	Omar Bin Abed AlAziz St	).667	515	3.56	8664	34	150	1
18	Abedel Hameed Sharaf St	l.667	432	3.19	18298	20	190	0
19	Queen Noor Al Hussain St	l.000	380	3.34	16034	30	190	0
20	AL- Quds Street	l.000	550	3.59	13830	30	1100	0

APA= annual pedestrian accidents

INTr3= Local integration values R3

ADT= Average Daily Traffic Volume (Vehicle/ peak hour)

* Sidewalk condition; 0 = width>2m (good condition), and 1= width<2m (bad condition).

Table 4: 20 Streets assigned for modelling pedestrian accidents.

A multivariate stepwise regression analysis was implemented to investigate the association between independent variables included in the analysis and pedestrian accidents. Table 5 shows the variable correlations and the coefficients used to create the model prediction formula. The results show that traffic exposure values are highly significant independent variables that explain accident rate in selected street samples. The predicted model shows that as the traffic volume increased the accidents rate increased. The marginal effects showed that the increase from 280 vehicles to 290 vehicles per hour, for example, increased the likelihood of a pedestrian accident occurrence by 2.02 per cent. (See Model 3)

<u>Model (3): The regression equation is:</u>

APA = 0.148 + 0.00069 ADT; R-Squared = 0.622 ……………… (3)

The inclusion of pedestrian volume values increased the coefficient of determination to 0.712 (P value = 0.08). The model also found that pedestrian volume, while higher at the accident sites, was negatively correlated with pedestrian accidents in this particular sample of sites. The predicted model shows that as the number of pedestrian increased the accident rate decreased. The predicted model yields the following results:

<u>Model (4): The regression equation is:</u>

APA = 3.298 + 0.00043 ADT – 0.850 INTr3; R-Squared = 0.712 ……………… (4)

Model Summary

Model	R	R Square	Adjusted R Square	Std. Error of the Estimate
1	.789[a]	.622	.601	.31205
2	.844[b]	.712	.678	.28035

a. Predictors: (Constant), TRAFFIC

b. Predictors: (Constant), TRAFFIC, INTr3

Coefficients[a]

Model		Unstandardized Coefficients		Standardized Coefficients	t	Sig.
		B	Std. Error	Beta		
1	(Constant)	.148	.186		.796	.436
	TRAFFIC	6.993E-5	.000	.789	5.443	.000
2	(Constant)	3.298	1.378		2.392	.029
	TRAFFIC	4.294E-5	.000	.484	2.609	.018
	INTr3	-.850	.369	-.427	-2.302	.034

a. Dependent Variable: ACCIDNT

Table 5: Model variables summary and coefficients

Previous studies have also found that traffic volumes have a positive relation with pedestrian accidents, and that pedestrian accidents frequency increases as the number of traffic passing the street goes up (Ekman, 1996; Leden, 2002). Moreover, pedestrian volumes have also been identified as one indicator for accidents occurrence. Most published studies agree that pedestrian volume has a nonlinear relation with pedestrian accidents and that as the number of pedestrians increased the number of accidents decreased. This is referred to as the “safety in numbers” effect (Leden, 2002; Miranda-Moreno et al., 2011). Jacobsen, P.L., (2003) examined the relationship between the numbers of people walking or bicycling and the frequency of accidents. He found that vehicle drivers adjust their behaviour in the presence of people walking and bicycling. Therefore, a motorist is less likely to collide with a person walking and bicycling when there are more people walking or bicycling (Jacobsen, 2003, p. 208) (Figure 4).

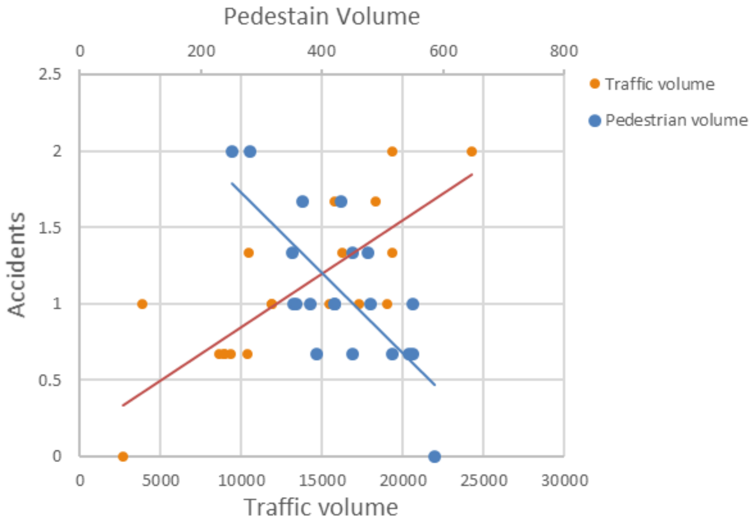


Figure 4. The relationship between traffic and pedestrian volumes and accidents

3.2.1 Verification of the pedestrian accident prediction model

The research verified the accident prediction model developed previously in Model (4) by selecting 15 new streets. An initial test was shown to be significant, with some trivial changes to the coefficients. The result of this model was a correlation of r-squared = 0.60, as shown in Figure 5 below.

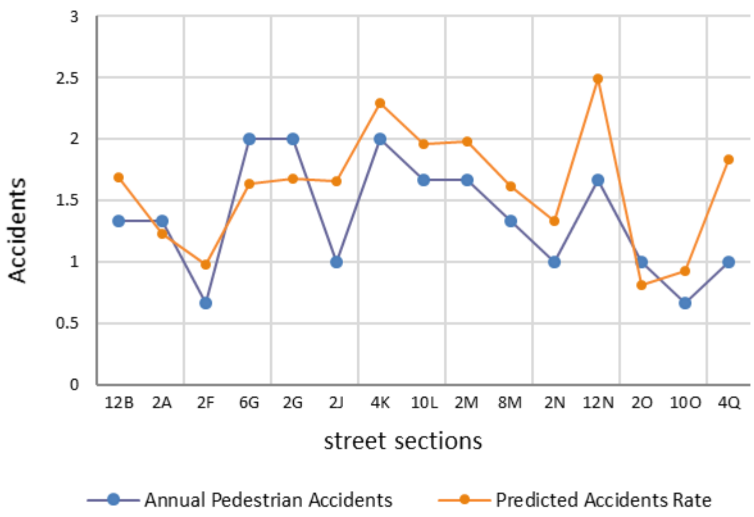


Figure 5. Values between forecast and observed pedestrian accidents in the Irbid pedestrian accidents model.

3.3 Stage 3: Estimate pedestrian exposure and risk

The final step in the pedestrian-risk analysis was the comparison of pedestrian volumes to pedestrian collision data provided by the Jordan Traffic Administration Department. Three years of pedestrian accident data were added to the GIS. A total of 620 accidents at 60 different streets were utilized over a three-year period between 2005 and 2007. The total number of collisions at each street was divided by three to determine the average annual collision rate.

- **Calculation of Risk**

The final Relative Pedestrian Risk Index was created using the simple equation included in the following:

- **Relative Risk = APA/APPV ………………………………………………………… (5)**

Where; APA = Annual Pedestrian – Vehicle Collisions.

Calculated risks were represented in the Figure 6 map which shows pedestrian accident risk represented by bars. The axial lines in the map vary in thickness and colour where red lines represent highly integrated street segments and blue lines represent segregated street segments.

3.4 Hotspots

In this research, hotspots are defined as the locations where there is a high level of risk as a function of annual pedestrian accidents divided by predicted peak-hour pedestrian rates. The research shows that 80 per cent of hotspots are arterial roads outside the city centre, and 60 per cent are commercially used, that witness heavy traffics. For example, commercial streets; King Abdullah II and Rateb Bataineh streets witness 26498 and 25393 car per day respectively, and these streets found to be high risk streets for pedestrian. Road characteristics present an important factor affecting pedestrian safety. Studying hotspots shows that 80 per cent of the roads have a no pedestrian crosswalks, or if they exist, they invisible or unused. Road width was an important aspect; it can be seen clearly that when the road width increases, the probability of pedestrian accident occurrence also increases incautiously. As mention before large per cent of high-risk streets are streets located outside city centre which are also considered high speed locations; the speed will increase the probability of accidents as previous literature indicated. The drivers think that these areas do not have pedestrian crossing, contrary to the city centre that suffers from congestion.

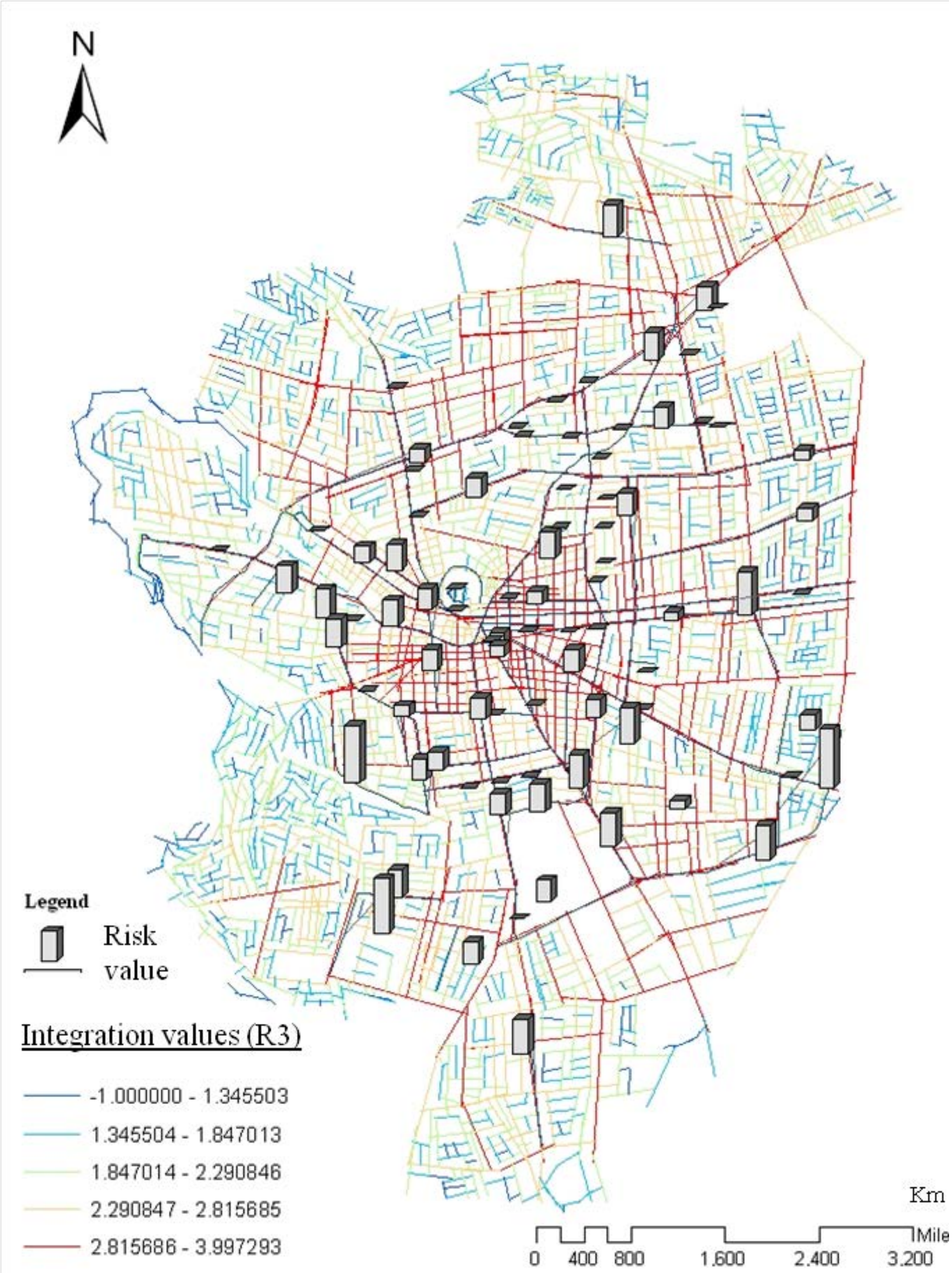


Figure 6. Irbid pedestrian accidents risk and axial map. Source: (Author).

4. Findings and recommendations

4.1 Findings

Of particular interest in the study was the significant relationship between integration values and pedestrian volumes. The analysis shows a strong relation between the measured local integration values (R3) and those of the existing pedestrian volume in the field. The predicted model yields a coefficient determination r-square = 0.745 at a 5 per cent level of significance. The inclusion of a land use variable increased the coefficient determination to 0.80. This model also shows that pedestrian volume is directly proportional to land use type. The predicted models for pedestrian accidents indicate that average pedestrian accidents are highly and directly correlated with the average daily traffic volume and negatively correlated with pedestrian volume at selected samples. As total pedestrian movement decreases and average AADT increases, expected numbers of accidents also increase. The predicted model yields a coefficient of determination r-square = 0.86 at a 5 per cent level of significance.

The coefficient of road width and road length was also positive, however, the best fit for model included a linear term, indicating that the number of accidents increased as traffic volume increased. The coefficients of pedestrian volume (which also included a linear term) indicate a negative relationship with pedestrian accidents. It is possible that where pedestrian volume is higher, vehicles use lower speeds because of traffic congestion, leading to fewer pedestrian accidents.

4.2 Recommendations

Improving pedestrian safety in Irbid city requires consideration of three main elements: driver, pedestrian, and roadway/land use planning characteristics. While many studies consider the role of the physical environment, few examine the impact of social environments, and access to pedestrian and driver behaviour. As this research was limited to physical measures. In-depth research is needed on the interaction between these physical and behavioural aspects.

In addition, our understanding of pedestrian risk is limited by incomplete data on pedestrian exposure, and limited data on pedestrian accidents. Currently, police reports of pedestrian-vehicle accidents provide little information about road characteristics, driver behaviour, and pedestrian behaviour or even exact location. These variables are critical to a deeper understanding of pedestrian accidents. Efforts also should focus on developing a standard measure of pedestrian risk, such as accidents per walk trip or accidents per time spent walking or per distance walked. A standard measure of accidents risk would greatly improve our ability to compare research results and analyse accident across time and place. Roadway and land use planning characteristics can provide safer environment for pedestrians by considering the engineering planning standards.

References

Ekman, L. (1996). *On the Treatment of Flow in Traffic Safety Analysis,-a non-parametric approach applied on vulnerable road users.* Lund University.

Greene-Roesel, R., Diogenes, M. C., & Ragland, D. R. (2007). Estimating Pedestrian Accident Exposure: Approaches to a Statewide Pedestrian Exposure Database. *Safe Transportation Research & Education Center*.

Hillier, B. (1996). *Space is the Machine*: Cambridge University Press Cambridge.

Hillier, B., & Hanson, J. (1984). *The social logic of space* (Vol. 1): Cambridge university press Cambridge.

Hillier, B., & Hanson, J. (1984). The social logic of space CUP: Cambridge.

Hillier, B., Hanson, J., & Graham, H. (1987). Ideas are in things-An application of the space syntax method to discovering house genotypes. *Environment and Planning B, 14*(4), 363-385.

Hillier, B., & Vaughan, L. (2007). The spatial syntax of urban segregation. *Progress in Planning, 67*, 205-294.

Ismail, K., Sayed, T., & Saunier, N. (2009). *Automated collection of pedestrian data using computer vision techniques.* Paper presented at the Transportation Research Board Annual Meeting Compendium of Papers, Washington, DC.

Jacobsen, P. L. (2003). Safety in numbers: more walkers and bicyclists, safer walking and bicycling. *Injury prevention, 9*(3), 205-209.

Kennedy, J. F. (2008). *Estimating pedestrian volumes and crashes at urban signalized intersections.* Virginia Polytechnic Institute and State University.

Kim, D.-J., Ko, J., & Lee, Y.-i. (2013). *Estimating Pedestrian Traffic Volume: A Preliminary Analysis.* Paper presented at the Proceedings of the Eastern Asia Society for Transportation Studies.

Leden, L. (2002). Pedestrian risk decrease with pedestrian flow. A case study based on data from signalized intersections in Hamilton, Ontario. *Accident Analysis & Prevention, 34*(4), 457-464.

Liu, X., & Griswold, J. (2009). Pedestrian Volume Modeling: A Case Study of San Francisco. *Yearbook of the Association of Pacific Coast Geographers, 71*(1), 164-181.

Miranda-Moreno, L. F., Morency, P., & El-Geneidy, A. M. (2011). The link between built environment, pedestrian activity and pedestrian–vehicle collision occurrence at signalized intersections. *Accident Analysis & Prevention, 43*(5), 1624-1634.

Organization, W. H. (2013). *WHO global status report on road safety 2013: supporting a decade of action*: World Health Organization.

Penn, A., Hillier, B., Banister, D., & Xu, J. (1998). Configurational modelling of urban movement networks. *Environment and Planning B-Planning & Design, 25*(1), 59-84.

Raford, N., & Ragland, D. R. (2003). Space Syntax: An innovative pedestrian volume modeling tool for pedestrian safety.

Raford, N., & Ragland, D. R. (2005). Pedestrian Volume Modeling for Traffic Safety and Exposure Analysis. *Safe Transportation Research & Education Center*.

Rashid, M. (2012). On space syntax as a configurational theory of architecture from a situated observer's viewpoint. *Environment and Planning B, 39*(4), 732.

Sailer, K., & McCulloh, I. (2012). Social networks and spatial configuration—How office layouts drive social interaction. *Social networks, 34*(1), 47-58.

Schneider, R. J., Arnold, L. S., & Ragland, D. R. (2009). Pilot model for estimating pedestrian intersection crossing volumes. *Transportation Research Record: Journal of the Transportation Research Board, 2140*(1), 13-26.

Turner, A. (2004). Depthmap 4: a researcher's handbook. University College London.

Zegeer, C. V., Stewart, J. R., Huang, H. H., Lagerwey, P. A., Feaganes, J., & Campbell, B. (2005). Safety effects of marked versus unmarked crosswalks at uncontrolled locations: Final report and recommended guidelines.